POWER QUALITY IMPROVEMENT OF SINGLE PHASE GRID CONNECTED PHOTO VOLTAIC SYSTEM

A thesis submitted in partial fulfilment of the requirements for the degree of

Master of Technology

In

Electrical Engineering

(Specialization: power electronics and drives)

By

Kesana Raveendra

Under the guidance of

Prof. P.K.Ray

Department of Electrical Engineering

National Institute of Technology, Rourkela

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CERTIFICATE

This is to certify that the project entitled, "power quality improvement of single phase grid connected photo voltaic system" submitted by Kesana Raveendra in "power electronics and drives specialization is an authentic work carried out by him under my supervision and guidance for the partial fulfilment of the requirements for the award of Master of Technology in Electrical Engineering during the academic session 2014-15 at National Institute of Technology, Rourkela. The candidate has fulfilled all the prescribed requirements. The Thesis which is based on candidate's own work, has not been submitted elsewhere for any degree. In my opinion, the thesis is of standard requirement for the award of a Master of Technology in Electrical Engineering.

Date: **Dr. P.K.Ray**

Place: **Dept. of Electrical Engineering**

ACKNOWLEDGEMENT

I would like to express my heartfelt gratitude and regards to my project guide, Prof. P.K.Ray, for being the corner stone of my project. It was his incessant motivation and guidance during periods of doubts and uncertainties that has helped me to carry on with this project.

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Finally I would like to express my gratitude towards my family, for their constant support for me in every aspect.

Kesana Raveendra
213EE4318

Dedicated to my Family

ABSTRACT

Power quality which involves power factor and the current wave form mainly affected by the power electronic loads which are connected to the grid. In this work reactive power compensation theory is applied to the inverter which feeds the power to the grid from the solar grid. Solar cell works on the principle of photo voltaic effect, which has nonlinear voltage and current characteristics. These characteristics are improved with the help of maximum power point tracking (MPPT) controller. MPPT controller helps to feed the inverter with maximum power from the solar grid. The Mat lab/Simulink model for the photo voltaic cell are implemented, MPPT controller has been modeled for driving the boost converter. MATLAB/simulation results are verified for the single phase grid involves the current waveform and total harmonic distortion level.

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Chapter-1

Introduction

Solar cells converts solar energy into electrical energy, these photovoltaic cells are essentially electronic devices. Photo voltaic cells do not have the capability of storage capability, but this storage can be provided using batteries.

These Photovoltaic(PV) cells converts most abundant and freely available solar energy into electrical energy without causing any harm to the environment, where as in the case of thermal plants produces harmful gasses into the atmosphere .

PV cells produce electricity without having any mechanical rotating part, thereby the losses with this type of generation are very less. The voltage generated by this solar cells is analogous to that of battery. The voltage and current ratings of the solar cell can be increased by connecting positive and negative leads of cell in series and parallel combination.

PV panel is a combination of PV cells in series and parallel connection, the PV module is a combination of some PV panels. Commercial and industrial solar power system installation string voltages may vary from 300-1000 V and currents of the range 5-10 A.

1.1 Literature review

The simulation of solar cell and the power quality improvement survey is done in the fallowing way. Ramakishan et.al[11] has implemented the simulation cell modelling using single diode model representation, the results are verified using MATLAB/Simulink. Xuosong zhou et.al[12] has given the detailed information regarding the implementation of maximum power point tracking method and compared the results. Hamad et. al [1] has given the detailed information regarding the connection of solar cell to the grid and to improve the power factor using fuzzy logic controller. Kelesidas.K et. al[4] discussed about the p-q based reactive power compensation theory. Which is required for the linear and nonlinear type of loads. This theory gives the detailed information about the compensation of reactive power requirement at the load side, this theory can give the detailed information regarding the compensation of harmonic component of current. The simulation of the solar using simscape model is guided from N.C.sahoo et.al [13], gives the brief description of how to model the solar cell using MATLAB/Simulink using simscape. The maximum power point application to the solar cell using MATLAB/Simulink is guided effectively K.Prabha et. al [8], gives the brief modelling reference for maximum power point technique. The filtering of harmonics presented in the load when nonlinear loads are used, can be eliminated using filtering Jinjun et. al [6],[8], gives the filtering circuit for the elimination of harmonics. The Maximum power point tracking using perturb and observe method is simulated by taking reference B.Subuddi et. al[2],[14] gives the brief description of different types of mppt techiniques, and the implementation of maximum power tracking using MATLAB/Simulink method. And he boost converter operation and the control using maximum power point technique is effectively taken using Y. Zhihao et. al [15], gives the brief description about the boost converter operation and its application to raise the voltage level, from existing voltage. The inverter operation and its connection to the grid is given using hamad et. al[1]. This is about the literature survey regarding the power quality improvement of single phase grid connected grid connected photo voltaic system.

1.2 Motivation

The demand for the electrical energy increasing every day, and the availability of fossil fuel sources declining day by day, this made me to think about alternative energy source solar energy. A lot of research is being going on this area, but still the effective utilization of solar energy is not happening. This thing motivates me to work on extract maximum power from the solar cell, and to connect the solar cell effectively to the grid, and to contribute my way of thoughts towards the power quality improvement of the system, when a solar cell is connected to the grid.

1.3 Objectives

i. Simulation modeling of photovoltaic cell using direct simulation method, diode model, simscape model and observing the characteristics.
ii. Simulation model of maximum power point controller with boost converter topology and connecting to the single phase grid.
iii. Power quality improvement using reactive power compensation theory for linear and nonlinear type of loads.

1.5 Thesis layout

This work completely describes the operation of the photovoltaic cell and the conversion of solar energy to electrical energy.

Chapter two gives the brief description of the photo voltaic cell operation, equivalent circuit of the solar cell and the important characteristics in the equivalent circuit. The important parameters that effect the operation the photovoltaic cell operation are described.

In chapter three, it gives the complete description about how the maximum power can be extracted from the solar cell is given. And the different methods for getting the maximum power from the solar cell are described. The description about the incremental conductance method and the perturb and observe method.

The chapter four gives the description about the boost converter circuit and inverter. The boost converter operation in on and off operations is explained. The boost converter operation supported by wave forms. The inverter operation also explained in the chapter four, supported by the diagrams and waveforms.

The chapter five explains the theory relating the reactive power compensation theory. The compensation of the harmonic current with the inverter compensating current is explained. With the help of the block diagram, the operation is explained briefly.

The chapter six explains the simulation results obtained from the simulation of solar cell, and its characteristics at different atmospheric conditions are also checked. The results obtaining after applying the reactive power compensation are also checked.

CHAPTER-2

Description of photovoltaic cell

2.1 Introduction

Commercial available PV panel used in most of the solar power station ranges 12,24,48,96 V.

Advantages of PV system generation are

I. Simplicity of the power generation.
II. Absence of the fuel cost for power generation.
III. Lack of noise due to absence of moving parts.
IV. Clean, pollution free and inexhaustible energy source.
V. Declining cost and prices of solar modules and increase of efficiency
VI. High dependability.

Applications of Solar power:

I Water pumping

II. Street lighting in rural town applications.

III For satellite power feeding applications.

IV Can feed the grid connected system

Commercial available connection of PV cell

The commercial available circuit of the solar cell with the grid is shown as below. The circuit contains collection of PV cells known as PV module connected to dc grid. The dc available power is converted into ac power using inverter circuit. The available ac power will be fed to the loads available in its surroundings.

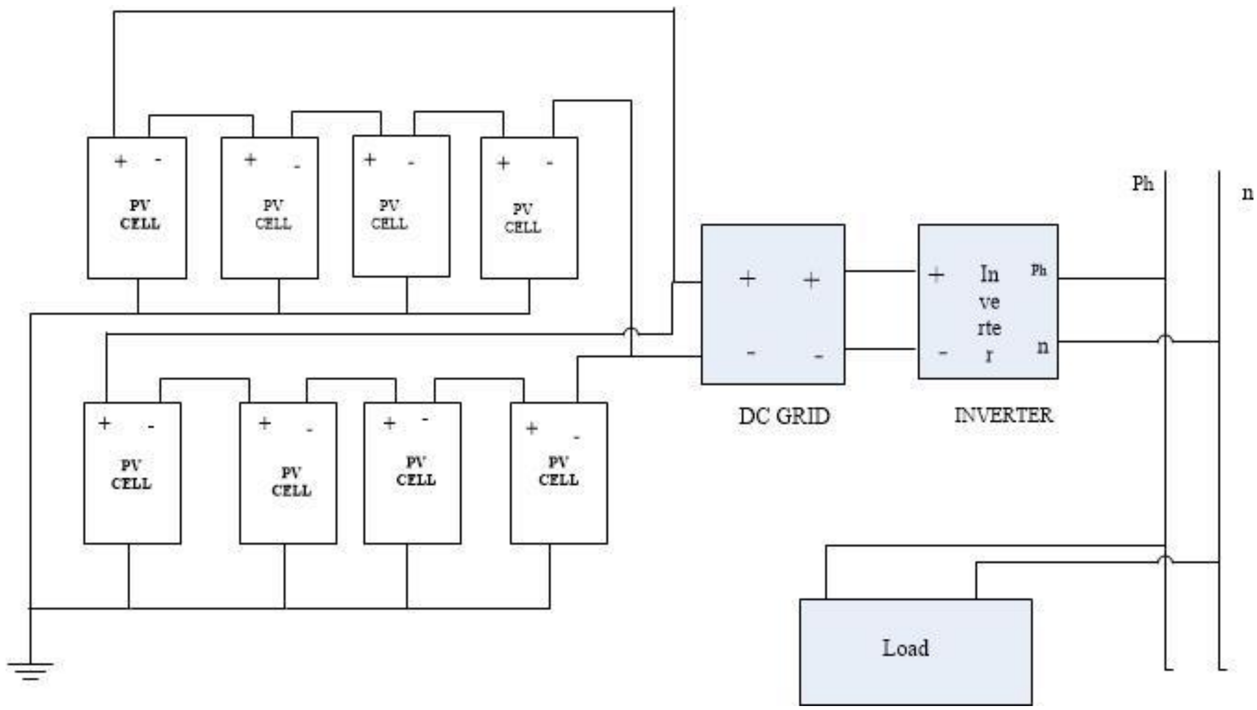

Fig.2.1. Commercially available connection of the solar cell

2.2 Solar cell modelling

Solar cell can be modelled as current source (Iph) in parallel with Diode (D), Shunt resistance (Rsh) and series resistance (Rse).Current and voltage profile of the solar cell depends on Atmosphere temperature (T), and irradiance (S). The output power of Photo voltaic cell is given by P=V*I. The current produced by the PV cell is equal to the current produced by the current source minus the diode and shunt resistance current. The light generated current of Photo voltaic cell depends on the solar irradiation and the temperature

$$I = Iph - Id - Ish \text{ ....} \quad (1)$$

$$Iph = [Isc + Ki * (T - Tr)] * \frac{S}{1000}\ ] \quad (2)$$

$$Id = Io(e^{\frac{q(v+i*Rs)}{AKT}} - 1) \quad (3)$$

$$Io = Ior * \left(\frac{T}{Tr}\right)^3 * (e^{\frac{q*Eg*\left(\frac{1}{Tr}-\frac{1}{T}\right)}{A*K}}) \quad (4)$$

I=output current of the PV cell.

Iph=cell generated current

Id=Diode current

Ish=current drawn by the shunt resistance

Isc=short circuit of the PV cell.

Ki=short circuit temp coefficient of cell (0.0032A/k (approx...))

T=module operating temperature in kelvin

Tr=reference temperature in kelvin=298k

Q=charge of electron=$1.9 * 10^{-19}\ C$

S=module irradiance ($^{w}/_{m^2}$)

Eg=energy band gap=1.1ev

A=ideality factor=1.6

K=Boltzmann constant=$1.38 * 10^{-23}$

The important parameters of solar cell are open circuit voltage (Voc), short circuit current (Isc), Maximum Output power (Pmax).

2.3 Equivalent circuit

Here Is is the source current or the solar cell current which is of nearly constant. Id is the diode current, Diode is placed in parallel to ground the cells which are which are effected by the unshaded portion of the sun irradiation. Rsh is to to represent the leakage current that is presented in the cell which is the order of 1000 ohms. Rse is the series resistance to replace the losses present the cell. Vo is the output voltage or the open circuit voltage presented, at the terminals of the cell. Io is the current available at the output of the cell. The equivalent circuit of the solar cell is shown as below

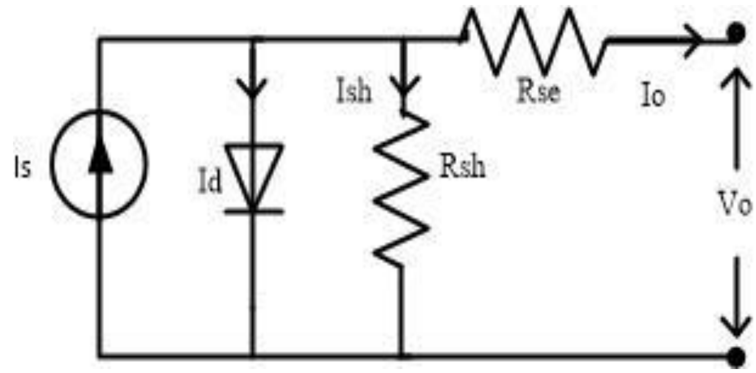

Fig.2.2. Equivalent circuit of PV cell

The source current generated the cell is constant, as and when the temperature are constant. As the current generated by the cell depends on the temperature and the solar irradiation. The diode current has the steeply increasing characteristics, with the voltage. The output current is the combination of cell current and the diode current, it results in the nonlinear characteristics of the output current and the voltage. The source current and the diode current and the output current with respect to voltage are shown as fallow.

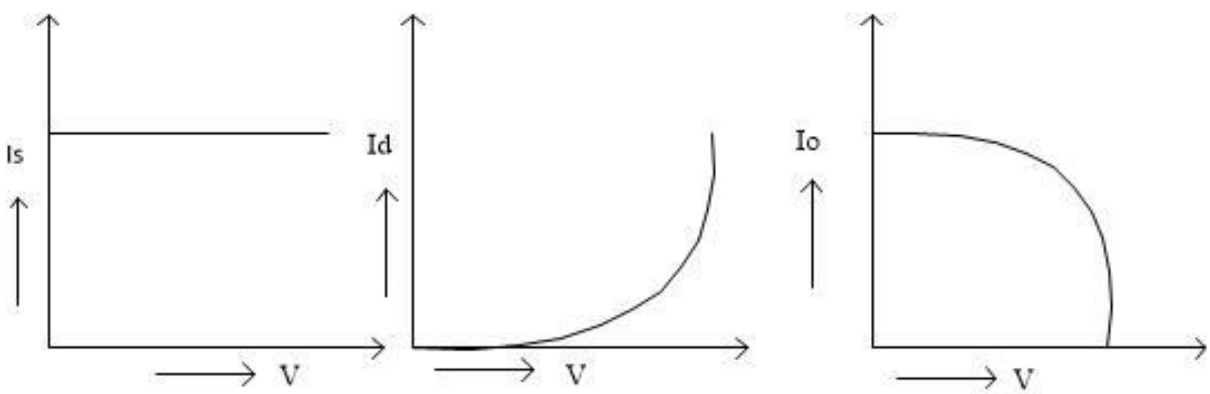

Fig.2.3. Cell current, diode current, output current with respect to voltage

2.4 Parameters of solar cell

2.4.1 Open circuit voltage (Voc)

Open circuit voltage is the no load voltage that appears across the terminals of the PV cell. Open circuit voltage voltage of the PV cell depends completely on the temperature (T).If the temperature of the PV cell increases then the output voltage of the solar cell or module decreases. By increasing the no of series cells we can increase the open circuit voltage of the solar module. Typically the open circuit voltage of the cell at temperature 25 degrees is about 0.6v for silicon cell.

2.4.2 Short circuit current (Isc)

Short circuit current of the cell is the maximum current that will flow under short circuit condition or zero voltage condition, and when the output terminals are short circuited. Short circuit current of the cell directly depends on the solar irradiance and reduces when the PN junction temperature decreases. Typical ratings of Short circuit current of PV panel ranges from 1-10 amps.

2.4.3 Series resistance (Rse)

Series resistance is placed in the model of solar cell to replace the losses occur in that. If the Rse increases then the losses, voltage drop increases. Which results in the sagging of current controlled portion of I-V curve. Loss due to PV cell is given by Vrse*Irse or $Irse^2 * Rse$. The value of the Rse is low and nearly less than 1 ohm.

2.4.4 Shunt resistance (Rsh)

The shunt resistance in the PV cell is to represent the leakage current occur in the cell, generally the value of Rsh is of high value of the order of thousands of ohms. Decreased in the value of Rsh results into the increase in the value of the leakage current, which results into the drop in the net output current intern reduces the open circuit voltage.

2.4.5 Reverse saturation current

When the output cell current of the PV cell increases then the Voc reduces because the cell temperature increases, there by the reverse saturation current of the cell increases. Reverse saturation current is effectively known as leakage current.

Chapter-3

Maximum Power Point Tracking Algorithms

3.1 Introduction

This chapter deals with the process of obtaining maximum power from the solar cell using maximum power technique. It explains the two important techniques incremental conductance method and perturb and observe method. The algorithms explains the process of getting maximum power from the existing system. The Mppt algorithm makes the boost converter to operate at its maximum operating power.

3.2 Maximum power tracking (MPPT)

The efficiency of solar cell is low, in order to increase the efficiency maximum power tracking algorithms are used, for getting maximum possible power from the varying source. In photo voltaic power generation the I-V characteristics are non-linear, there feeding power to a certain load. This can be improved by using Boost converter whose duty cycle is controlled by using MPPT algorithm.

The I-V ,P-V characteristics the solar cell are shown as the figure below,which are non linear in nature.The power is zero at the starting and at the final value of the curve.because the non occurrence of the maximum current and voltage at a same point.so as to maintain the operatint point at a maximum power value a specially designed technique is required that is maximum power point technique .

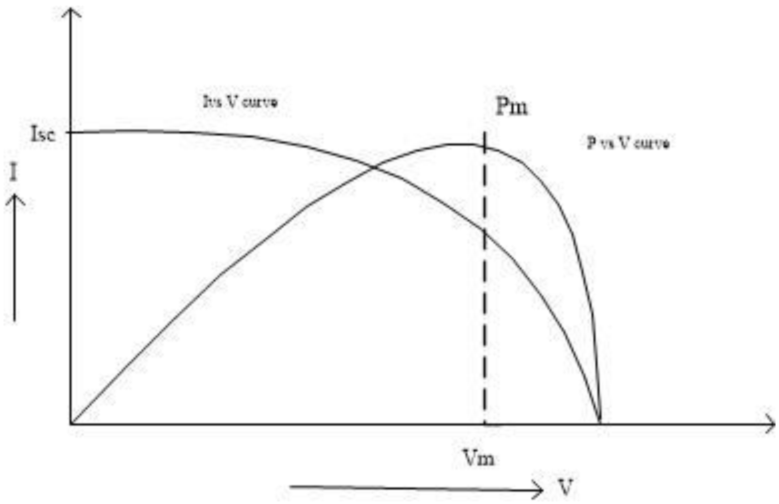

Fig. 3.1.I-V, P-V characteristics of the PV cell.

The point at which maximum value of current and voltage are obtained is known as maximum power point.

The maximum power point can be obtained by using the fallowing methods.

1. Incremental conductance method

2. Perturb and observe method.

3. Constant voltage method

4. Constant current method

5. Fuzzy logic controller method.

Here in this work, I fallow two methods incremental conductance method and perturb and observe method.

3.3 Incremental and conductance method

Power at the output terminals of the cell is given as P=V*I. Power versus voltage characteristics are nonlinear in nature ,so as to operate the cell at the maximum power point we are using this incremental conductance method. The maximum power condition is obtained when the slope of the power-voltage characteristics is zero. In this incremental conductance method conductance (I/V) of the cell is used as a reference to the value of (dp/dv).If the slope of the curve is equal to the conductance then we can say that the maximum power is obtained. If the (dp/dv) is greater than the (I/V) then we have to increase the duty cycle of boost converter. If the (dp/dv) is less than (I/V) then we have to decrease the duty cycle of the boost converter. This process takes place for repeated number of times and then the maximum power point achieves, the cell operates at that point only. So that the maximum power can be transferred to the load.

$$P = V * I \tag{5}$$

$$\frac{dP}{dV} = V * \left(\frac{dI}{dV}\right) + I\left(\frac{dV}{dV}\right) = 0 \tag{6}$$

$$V * \left(\frac{dI}{dV}\right) + I = 0 \tag{7}$$

$$\left(\frac{dP}{dV}\right) = -\left(\frac{I}{V}\right) \tag{8}$$

If this condition is reached, algorithm knows that MPP is reached and thus it terminates the process, it returns the corresponding value of operating point to MPP. This method exactly suits for the rapidly changing temperature and it is more accurate than perturb and observe method.

The algorithm corresponding to incremental conductance method is shown as below, which the duty ratio of the boost converter is controlled in corresponding to the condition of the MPP.

And it is explained as below.

$\frac{dP}{dv} = 0$ Then the Maximum power point has reached. That is the operating point, for that corresponding value the converter works and it delivers the maximum power to the load.

$\frac{dP}{dV} > 0$ Then the operating point is left of the maximum power operation. Then the operating voltage of the converter increased by increasing the duty cycle. A small incremental in the duty cycle is done and the corresponding value will be fed to the boost converter. And again it will check the condition, this process continues.

$\frac{dP}{dV} < 0$ Then the operating point is right of the operating point. Then the operating voltage of the converter has to be decreased by decreasing the duty cycle. A small decrement in the duty cycle is done and the corresponding value will be fed to the boost converter. This process continues for the next cycles till the MPP condition reached.

The flow chart diagram of how the perturb and observe method works and how the duty cycle will be changed is shown in the fallowing figure.

Characteristics of Incremental and conductance method

1. Control circuitry can be done with digital.
2. Incremental conductance method is expensive compared to other methods.
3. Complexity level in preparation of circuit is high.
4. It is used for the stand alone type of connections.
5. Converters used are DC-DC converters.
6. Best suits for the rapidly changing temperature conditions.
7. Control variables are voltage and current for this method.
8. Control strategy for this method is simple.

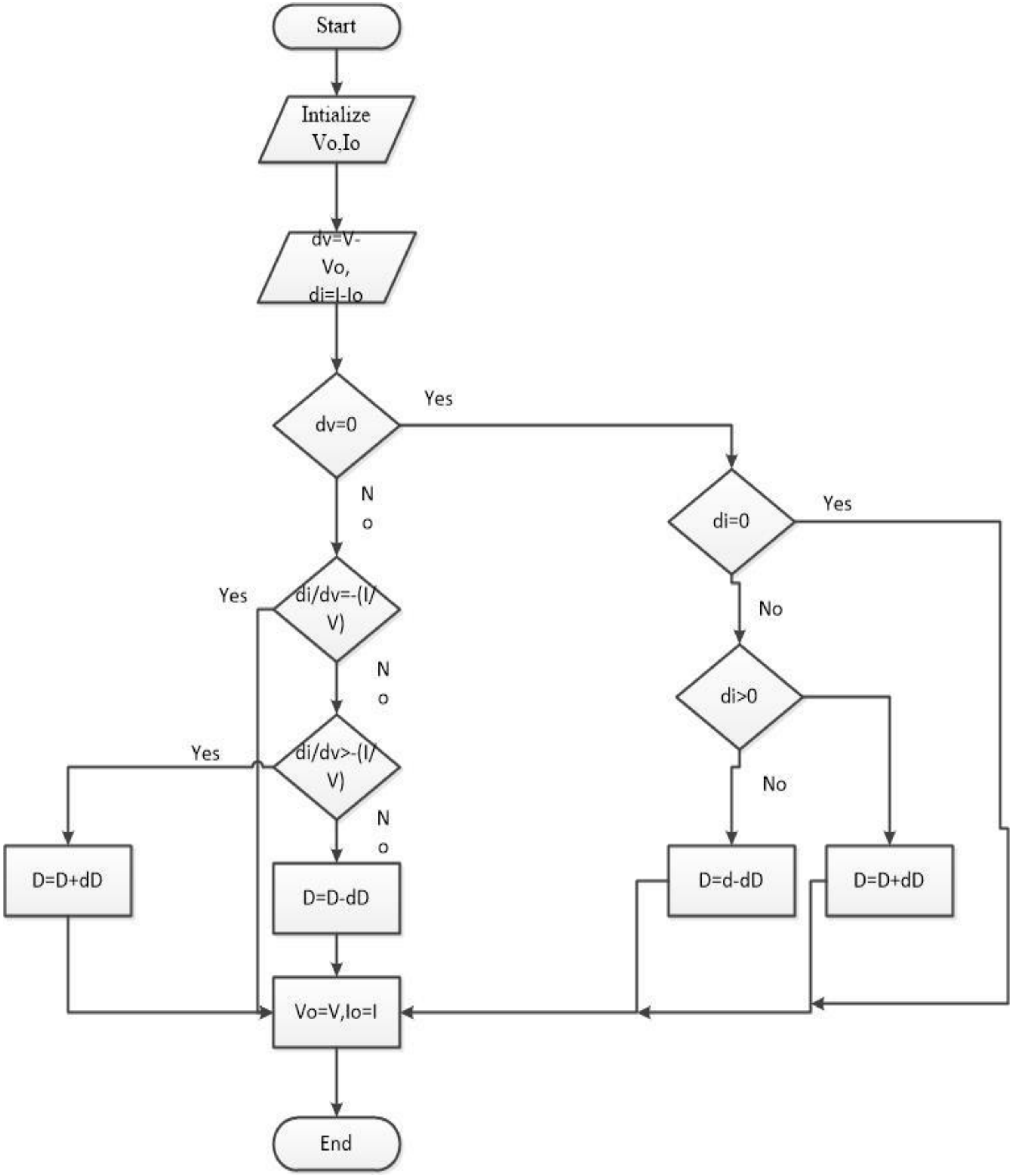

Fig.3.2. Flow chart diagram for incremental conductance method

3.4 Perturb and observe method

In the perturb and observe method directly power is mesured using voltage and current sensors.The power is calculated from the voltage and current values at Nth instant.By incrementing the values of duty cycle by a small ratio the voltage and current values will be measured at N+1 th instant.the power value at Nth instant and N+1 th instant will be compared.If the change in the power with respect to the is positive then the process is going in the correct direction, that is the positive direction. The duty cycle will be increased by a small ratio and the process will be continued for the next cycle. If the power with respect to voltage is negitive then the process is going after the maximum power in the negitive direction. In that case the duty cycle will be decreased and the values will be updated for the next operation.

$\frac{dP}{dV} = 0$ Then the slope of the characteristics is zero.The operation is taking place at the maximum power point . Then no cvorrection is required,the power supplied from the cell is the maximum value.

$\frac{dP}{dV} > 0$ The slope of the characteristic is positive, for getting maximum power operation the duty cycle of the converter will be increased,and the values of the voltage and current will be measured.The slope will be measured at the next cycles.

$\frac{dP}{dV} < 0$ Then the slope of the characteistics is negive. It is operating at a point after the maximum power point.For getting the maximum power operation the duty cycle of the converter will be decreased. And the voltage and the current values will be measured from them ,the power will be calculated.And this power will be compared with the previous value, this process will be continued for the next cycles.

Characteristics of perturb and obsreve method

1.Control strategy is simple for this method.

2.voltage and current are the control variables.

3.this method can be applied fo the analog and digital modes.

4.No parameter tuning is required.

5.cost for implementing this method is high.

6.complexity level of this circuit is high.

7.use ful for stand alone type systems

8.type of converters used are DC-DC converters.

9. Not suitable when the atmosphere conditions are changing rapidly.

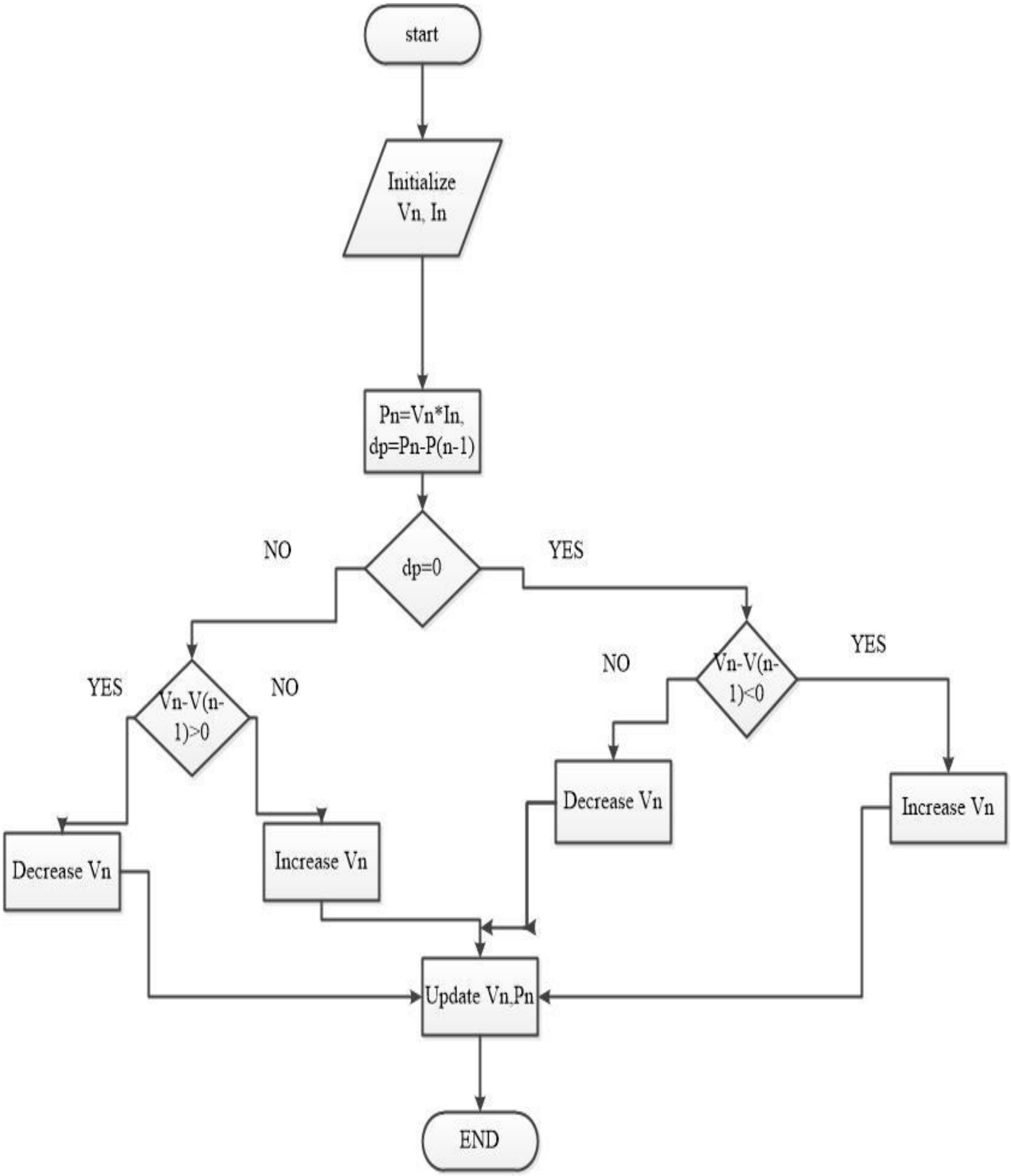

Fig.3.3. Flow chart diagram for perturb and observe method

CHAPTER-4

Boost converter and inverter

4.1 Introduction

This chapter deals with the operation of boost converter and the operation of inverter. The boost converter makes the output voltage of the converter to be greater than that of input which is required for the operation of inverter. The boost converter uses the maximum power point algorithm for getting triggering signal. The inverter converts the available dc input power into ac power at its output. This chapter explains the operation of boost converter and the inverter in its on and off modes. The theoretical diagrams for the operation are also given at the end for the analysis purpose.

4.1.1 Boost converter

DC-DC converters have huge applications in telecommunication, digital applications, software industry, and in the industrial applications. The output voltage after applying these converters may be high or low or equal to the supply depending on the type of the converters used.

For the boost converters the output voltage is greater than the input voltage which is required for the special type of applications. The basic boost converter consists of an inductor (Ls), power electronic switch, unidirectional diode, capacitor (Cl). The Duty cycle to the power electronic circuit can be varied using some specially designed firing circuit. Here we will give the firing to the converter using maximum power point tracking technique, which will drive the converter at its maximum power point operation.

4.1.2 Operation of the Boost converter

The electrical circuit of the boost converter is shown in the figure. The dc supply is connected to the inductor (Ls). When the power electronic switch is fired using the gating signal then the source is short circuited through the inductor. The stores the energy during the turn on process of the converter. In this turn on time capacitor at the load side feeds the load. When the power electronic switch is turn off then the load is connected through the source and the inductor.

The load is feed through the source and the inductor, makes the load voltage greater than the source voltage. The output voltage is in phase with the input voltage. The output voltage completely depends upon the duty ratio of the converter. If the duty ratio increases then the output voltage increases, if the duty ratio decreases then the output voltage increases.

When the power electronic switch is turned on then the current in the inductor increases. The slope with which the inductor current increases is given by

$$\frac{dIs}{dt} = \frac{Vs}{Ls} \qquad 9$$

In this situation the capacitor voltage is equal to the load voltage. The capacitor supplies the load current. The capacitor voltage is always greater the supply voltage. When the switch is opened the inductor current decreases. The voltage across the inductor is equal to (Vl-Vs).

4.1.3 Boost converter circuit

The boost converter circuit is shown in the figure, consists of dc source for supplying the power to the converter, inductor for storing energy in the form of magnetic field, Power electronic converter for the purpose of switching operation, unidirectional diode for separating source and load circuit, Capacitor for the purpose of continuous current operation, and load.

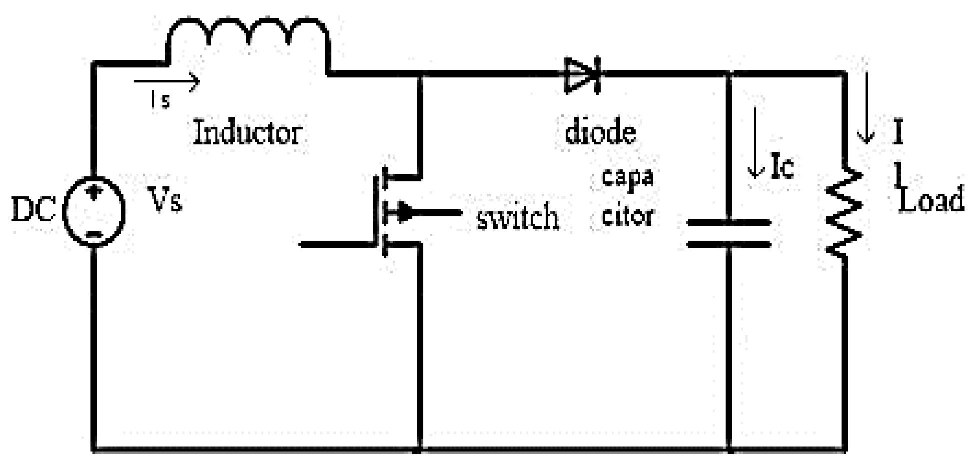

Fig.4.1. Boost converter circuit.

4.1.4 Boost converter during ON time

During the on time inductor is connected in parallal to the source. The voltage of the supply is equal to the voltage of the inductor. So as to maintain the voltage as constant the current will be steeply increasing in nature with slope of (Vs/Ls). The capacitor connected across the load. So as to maintain the load current as constat the capacitor supplies the load current required for the continous operation.The equavalant circuit of the boost converter during the on state is given in the fallowing figure.

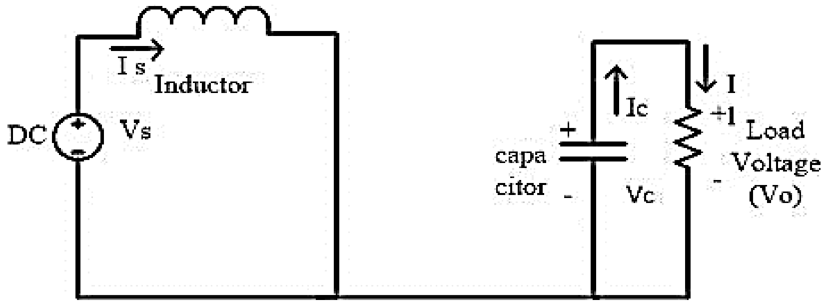

Fig.4.2. Equivalent circuit of boost converter during on time

4.1.5 Boost converter during off state

During the off state of the circuit both the source and the inductor combination is connected to the load, for supplying the high amount of energy to the load. Source current is the combination of both load current, capacitor current. The voltage across the inductor is resultant voltage due to source and load. The inductor voltage is of negative value as the load voltage is greater than the supply voltage, therefore the inductor current will be having current of decreasing slope equal to (Vc-Vs)/Ls. The current reaches the minimum value in this operation from its maximum value.

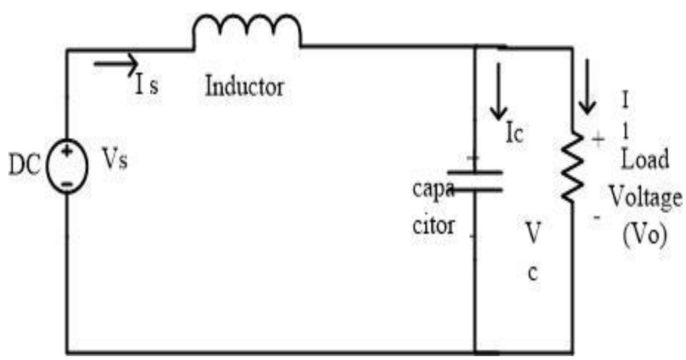

Fig.4.3. Equivalent circuit during off time

4.1.6 Characteristics of Boost converter

The switch current increases from minimum value of I min, and it reaches to maximum value of maximum value of I max, so as to maintain the voltage at constant value of Vs. The switch current remains zero during the off time of the switch. And the switch current again increases whenever the current in the switch turned on.

The diode current is zero during the on time of the power electronic switch. The voltage across the diode is negative due to the load voltage us greater than the source voltage, the current remains zero. When the mosfet is turned off the voltage across the diode is positive and the diode will turn on, the diode current is equal to the source current. The diode current during the off time equals to the sum of the load current and the capacitor current. The current will be zero as and when the the switch turns on, this process continues.

The inductor current presents always for the continues operation, the inductor current increases from minimum value whenever the switch turns on, with a slope of magnitude (Vs/Ls) and reaches to maximum value during the turn on process. As and when the switch turns off the current decreases from maximum value to minimum value with a slope of ((Vc-Vs)/ Ls), this process continues for the next values.

The inductor applies to a voltage of supply voltage during the turn on time, as the switch turn on and the diode is in off state. This voltage maintains the current in the inductor with linearly increasing value. The voltage applied across the inductor during the turn off process is the resultant voltage due to source and the load voltage that is (Vc-Vs) applied across the inductor. As the voltage across the inductor is negative the current of the inductor decreases with negative slope.

The variation of the switch current, source or inductor current, diode current, inductor voltage is shown in the fallowing figures.

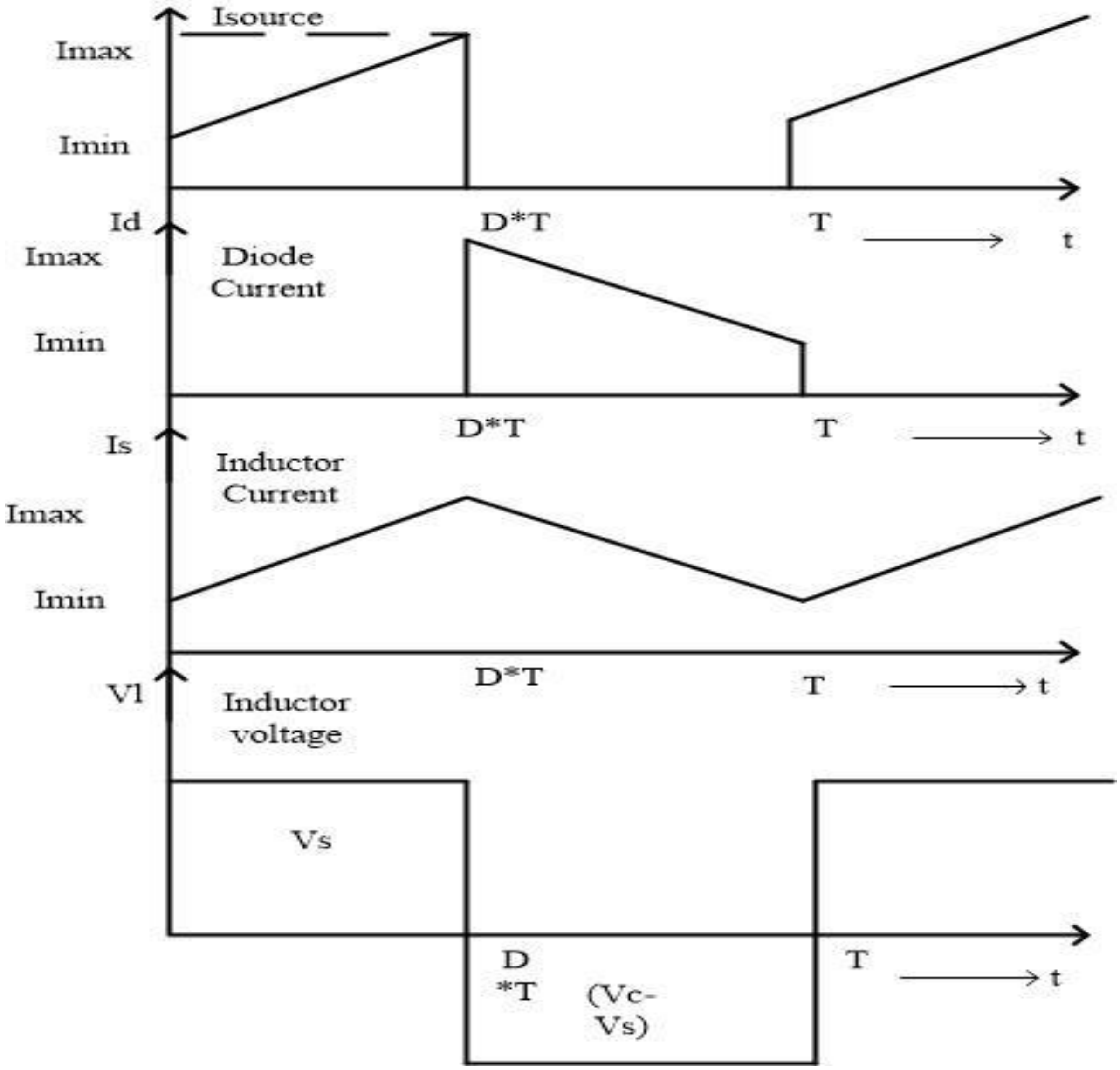

Fig.4.4. Waveforms of the switch current, diode current, inductor current, inductor voltage during turn on and off times.

4.2 Inverters

Inverters convert the Dc voltage available at its input to the ac voltage, which will be required for the purpose of loads. There are different types of inverters of the purpose of conversion depending upon the type of requirement. The main characteristics of the inverters are shape of the waveform, inverter efficiency. The inverter performance is characterized trough the fallowing properties total harmonic distortion, output power of the inverter. Square wave inverter is the basic inverter for the inversion purpose. The output of the inverter is square waveform, obtained from a constant dc voltage level. The circuit diagram of the basic inverter is shown as below.

The basic square wave inverter consists of four switches, S1, S2, S3, and S4. The Dc supply is given to the circuit. Initially the switches S1 and S2 are switched first, the output voltage of the circuit is positive. After some time the switches S3, S4 are given the triggering. The output voltage of this operation is negative. Together the output voltage is square waveform. This output voltage is having huge number of harmonics. This type of voltage applicable for the certain type of loads only, which doesn't involve the problem of harmonics. The characteristics can be improved by connecting unidirectional diodes in parallel to them. The connection can be useful for all types of loads. The square inverters can be implemented with less cost.

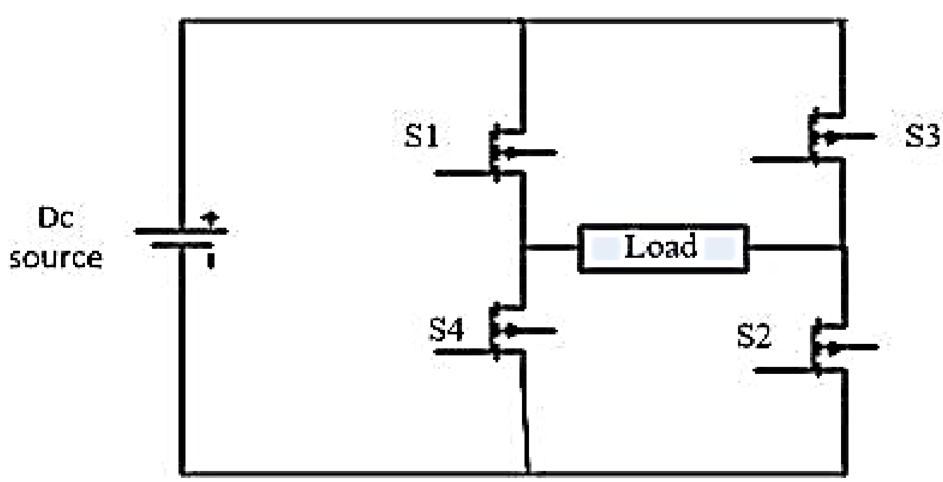

Fig.4.5. Basic inverter circuit of the inverter

The characteristics of the inverter can be improved using the fallowing circuit of operation. Any type of load can be fed using this type of connection. All quadrant of operations are possible. Forward motoring, forward braking, reverse motoring, reverse braking operations are possible by suitable switching the switches and diodes.

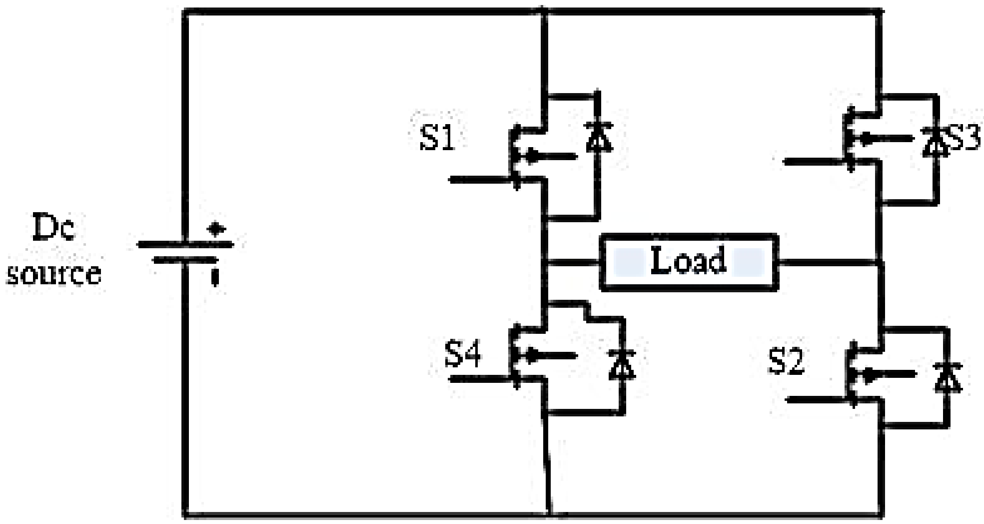

Fig.4.6. The inverter circuit

The wave forms for the inverter after applying the switching sequence is shown in the figure. The source is of dc supply voltage, which is always constant. The output voltage is of varying in magnitude from positive to negative that is output voltage is of square wave form is obtained. The square wave consists of full of harmonics, so as to feed the load it should be free from the harmonics. So as to free from the harmonics is applied to the filter circuit. So that the harmonics will be free from the output current wave form.

For the better operation the inverter circuit pulse width modulation circuit is used. Based on comparison of carrier signal with the reference signal firing pulses for the switches will be produced. The pulses will be fed to the power electronic switches. The output consists of less number of harmonics. The higher order harmonics can be easily eliminated using filter circuits.

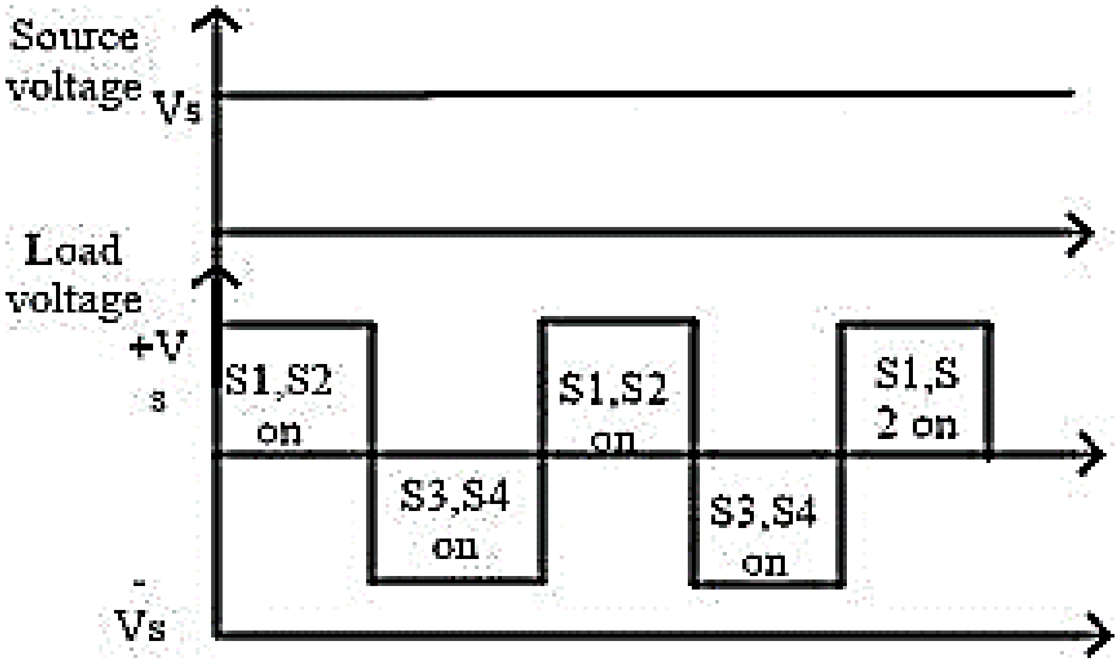

Fig.4.7. The input and output voltages of the inverter circuit.

The inverter with the combination of maximum power point tracking and pulse width modulation will definitely give good results compared to other methods.

The mppt is used for the purpose of obtaining maximum power from the circuit, and the pwm technique is useful for the purpose of elimination of harmonics.

The circuit diagram combining the both the PWM tequinique and mppt can be shown in the fallowing figure.

The combination of maximum power point tracking with the pulse width modulation is shown in the figure. The output voltage and current of the photovoltaic cell are sensed using the sensors and given to the maximum power point tracking controller , makes the output from the solar cell to be maximum. The output of the converter is fed as an input to the inverter circuit.

Pulse width modulation technique is applied to the inverter circuit for getting the triggering signals to the power electronic switches. The switches operate in a sequential manner to obtain the output voltage. The switches S1, S2 operate first for getting the positive half cycle of the output. The switches S3, S4 operate in the next instant for obtaining the negative half cycle of the output voltage. The triggering pulses for the switches will be given in sequential manner so as to obtain the output voltage. The switches S1, S2 operate for the positive half cycle of the output voltage.

In that time the switches S3, S4 remain in ideal operation, as the triggering pulses to these switches are supplied with the not gate from the triggering circuit. In the same way the triggering to the S1, S2 remain off when the switches S3, S4 are in operation. The output voltage for the corresponding Dc voltage will be a sinusoidal if the PWM is done in a proper way. The harmonics present in the output current can be reduced by using the proper filter circuit or any other compensation circuit. The output from the inverter is fed to the grid or standalone system. The output current consists of many unwanted harmonics, if the load is of power electronic type of load. The PV cell is used for the purpose of compensating the harmonic current present in the load. The output current should be controlled in proper way to obtain the so as to compensate the harmonic current present in the actual grid current. The filter circuit filters the harmonics present in the grid current using any available compensating circuit. One of such method is reactive power compensation theory (RPC).

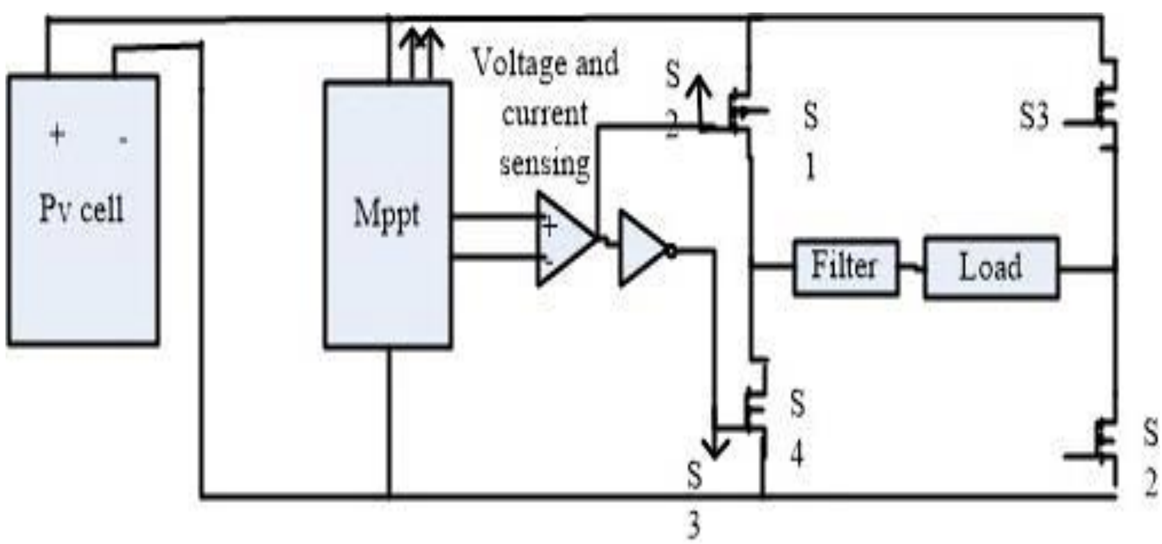

Fig.4.8. Circuit showing Mppt with inverter circuit.

Chapter-5

Reactive power compensation theory

5.1 Introduction

This chapter explains the operation of reactive power compensation theory. The harmonics present at the load side are mainly due to nonlinear loads present at the output side. The nonlinear loads involves the converters and inverters at the output side of the grid connected system. The reactive power compensation theory is one of the methods for the elimination of harmonics present at the output side of the grid. By controlling the triggering of the inverter switches for making the current to be in phase with the voltage.

5.2 Reactive power compensating (RPC) scheme

The load draws current of non-sinusoidal in nature. The current wave form at the grid effected by the load connected to it. The photovoltaic output converted into ac power and supply it to the grid. Besides to this property the harmonic current presented in the load can be controlled using proper controlling of the inverter current. If the harmonic current presented in the load is compensated by the solar cell current then the harmonics will be freed from the circuit. The actual thing that is happening here is the compensation of the reactive power taken by the load, with that of the reactive power generated by the solar cell.

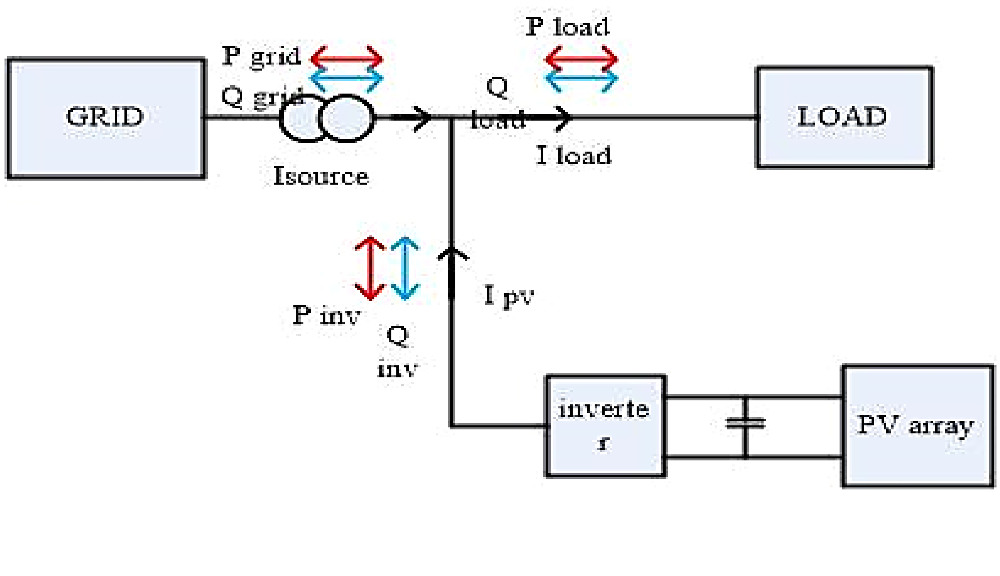

Fig.5.1. Block diagram view of the reactive power compensation system

In the reactive power compensation theory the actual currents in system are converted into α-β frame of reference. From this frame of reference the reactive power of the system is calculated. The reactive power of the inverter and the active power of the solar cell are obtained. Using these two values reference values for the currents in the α-β frame of reference are calculated. From α-β reference values the reference currents in the abc frame of reference will be obtained. From the reference value is given as the input to the hysteresis controller. The hysterics controller compares the actual value of the with inverter current. It produces the pulses required maintaining the current to be in phase with voltage. And the current consists of pure sinusoidal. There by this method suits better for the rectification of harmonics.

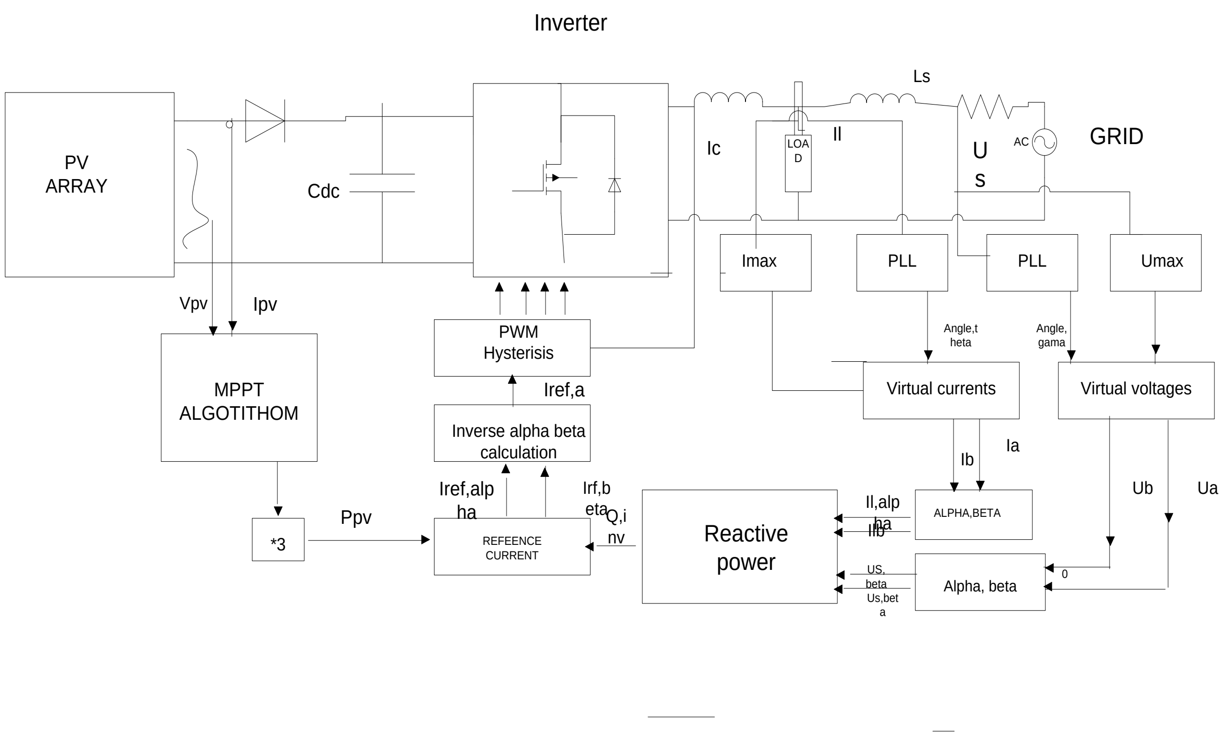

Fig.5.2. grid connection of photo voltaic system with reactive power compensation

The original p-q theory works forks for the three phase systems only. So as to obtain this theory to the single phase system we need to consider some virtual voltages and currents, which have the same magnitude but differ in phase by 120 degrees from one signal to another. This theory works in the αβ frame of reference. So we have to convert these values into the αβ frame of reference. The magnitude and phase angle values are measured using Phase locked loop. The actual signal is converted into two more virtual currents with the same magnitude and phase difference of 120 degrees. The currents and voltages obtained are given as Ia, Ib, Ic and Ua, Ub, Uc values. These obtained voltage and currents should be converted into αβ values using parks transformation. The αβ values of voltages and currents are shown as below.

The αβ frame of voltages are given by the fallowing equation (9).

$$\begin{bmatrix} U\alpha \\ U\beta \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} Ua \\ Ub \\ Uc \end{bmatrix} \tag{9}$$

The αβ frame of reference currents are given by the fallowing equation (10).

$$\begin{bmatrix} I\alpha \\ I\beta \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} Ia \\ Ib \\ Ic \end{bmatrix} \tag{10}$$

After calculating the values of voltages and currents in αβ frame, we have to calculate the reactive power taken by the inverter, it is given by the fallowing equation (11). This is the inverter is the value of the reactive power that is supplied.

$$q(t) = -U\alpha(t) * I\beta(t) + U\beta(t) * I\alpha(t) \tag{11}$$

The reference value in the αβ frame of reference is given by the fallowing equation. The Pinv is the value of the power applied to the inverter from the solar system.

$$\begin{bmatrix} Iref*,\alpha \\ Iref*,\beta \end{bmatrix} = \frac{1}{\alpha 2 + \beta 2} \begin{bmatrix} U\alpha & -U\beta \\ U\beta & U\alpha \end{bmatrix} \begin{bmatrix} Pinv \\ Qinv \end{bmatrix} \tag{12}$$

Here the value of the Pinv is given by the difference in the value of the solar power and the losses of the inverter. For the ideal inverter system loss power is given by fallowing equation (13).

$$Pinv = Ppv - Ploss \tag{13}$$

The Reference values of the currents in the actual frame is given by the inverse parks transformation. And the values of the reference is given by the fallowing equation (14)

$$\begin{bmatrix} Iref*,a \\ Iref*,b \\ Iref*,c \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} Iref*,\alpha \\ Iref*,\beta \end{bmatrix} \tag{14}$$

We need only one current required for the production of the triggering pulses to the inverter. So only Iref*, a is useful for the production of the pulse width modulation technique. Hysteresis controller is use for the purpose of generation of triggering pulses. The reference current is compared with the value of the inverter current. The obtained triggering pulses are given the switches using not gates. The sequence of operation makes the current to the sinusoidal.

Chapter-6

Results and Discussions

6.1 Introduction

This chapter gives the simulation MAT LAB results about the work that has been done. It gives the results about the photovoltaic cell characteristics, and the dependence of the results on the atmosphere conditions like temperature and irradiation. The results of the boost converter applying maximum power tracking technique, involving input and output voltage from the converter. It describes about the results relating to linear and nonlinear loads after applying reactive power compensation to the inverter and gives the results about the total harmonic results level.

6.2 Simulation results

6.2.1 I-V characteristics of PV cell

The current versus voltage characteristics of solar cell is a nonlinear curve. Because of the nonlinear occurrence of maximum and minimum values of current and voltage at a single point it is difficult to collect the maximum power from the solar cell. The simulation of solar cell can be done using different methods like direct simulation method, simscape method and diode equivalent method. The figure (6.1) shows the characteristics of solar cell, it has the short circuit current of 7.8 amps and open circuit voltage of 2.4 volts nearly.

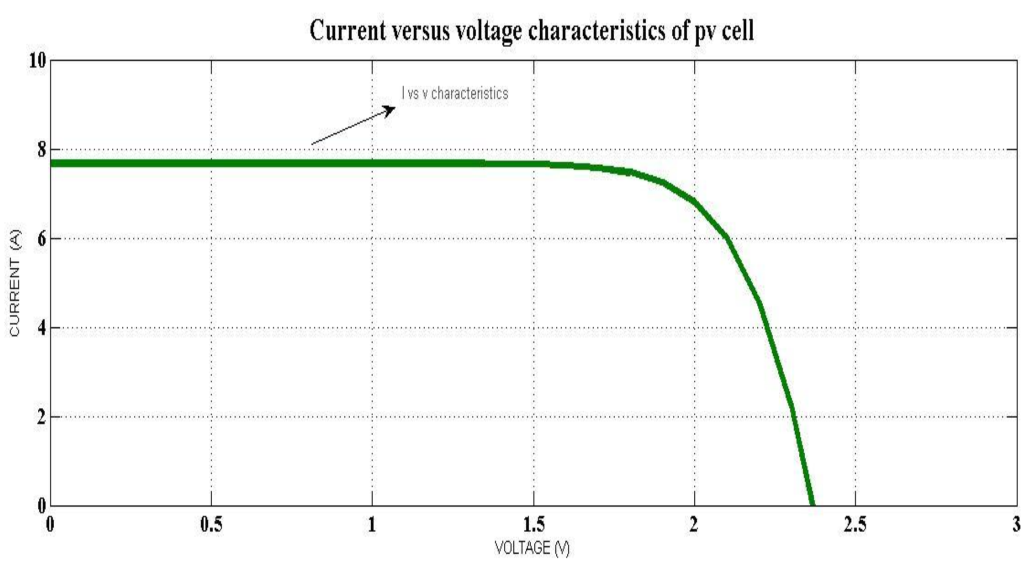

Fig 6.1 I-V characteristics of PV cell

6.2.2 Power versus voltage characteristics of solar cell

The power versus voltage characteristics of photovoltaic cell is a nonlinear curve which extends between zero voltage level to open circuit voltage level. The curve increase linearly from starting point to maximum value to maximum value and then it decrease to zero value. The maximum power occurs at at a voltage less than the open circuit voltage level. The nonlinear characteristics of the solar cell is due to nonoccurrence of maximum value of voltage and current and voltage at a single point. The figure (6.2) shows the variation of power with to voltage The maximum power is around 14 w occurs nearly at 1.9 volts

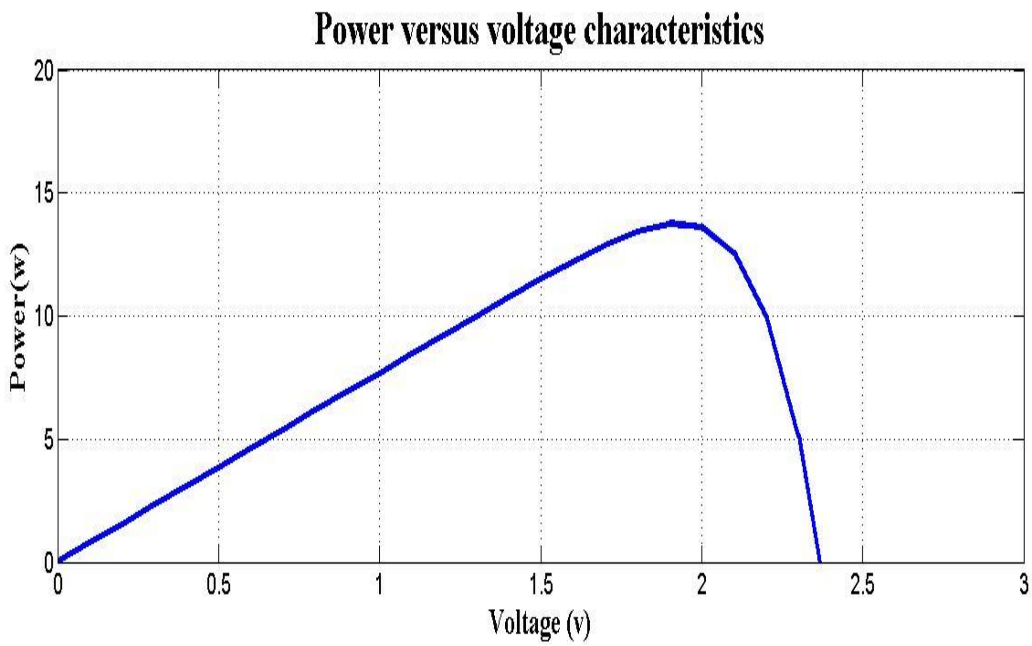

Fig 6.2 . Power versus voltage characteristics of solar cell

6.2.2 Variation of characteristics of solar sell with the variation in voltage

The characteristics of solar cell varies with varying in the sun irradiation level. As the irradiation level changes the corresponding current generated by the cell increases, as the current generated by the cell is a function of solar irradiance. There by the current voltage characteristics changes with the irradiance level. The fallowing two figures (6.3),(6.4) shows the effect of change irradiation with the change in the current versus voltage and power versus voltage characteristics. Both characteristics shows the improvement in the characteristics. The power and current increases appreciably at different irradiance levels.

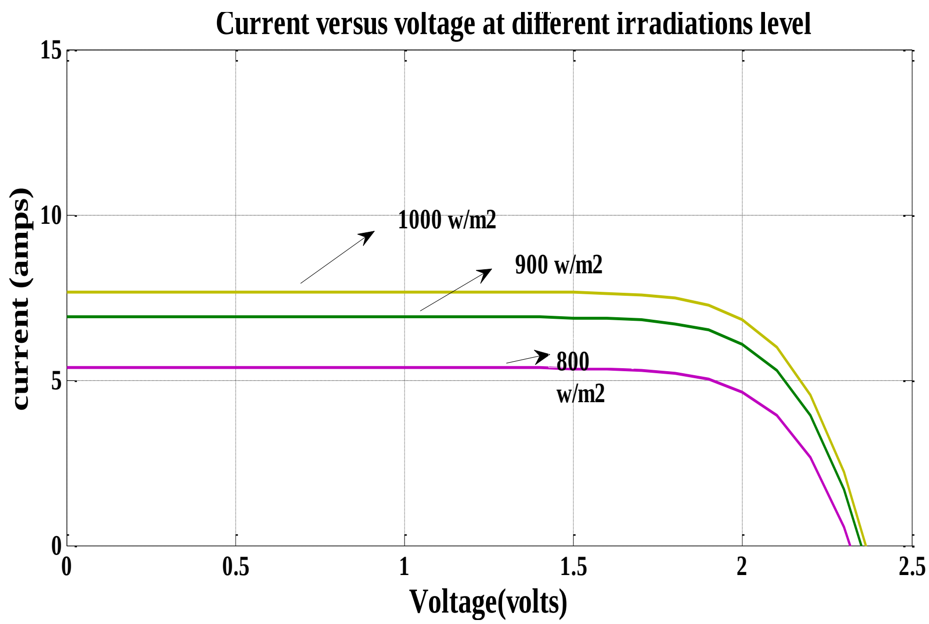

Fig 6.3. Current versus voltage at different irradiation levels

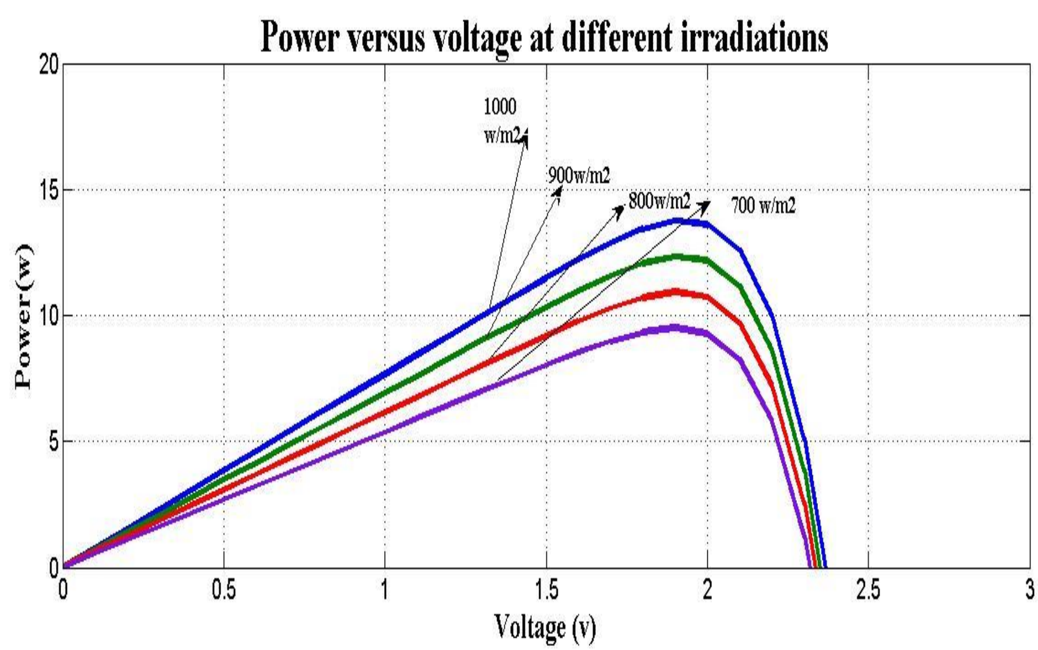

Fig.6.4. Power versus voltage at different irradiation levels

6.3 Voltage and current wave forms, Total harmonic distortion for linear load without using reactive power compensation

The current waveform obtaining from the grid for linear type load is shown in figure 6.5. The current waveform obtaining from is a wave deviating from unity power factor. The current wave form deviates from unity power factor because of inductive type of loads generally. The fallowing figure shows the nature of the current and the voltage wave form for a RL type of load.

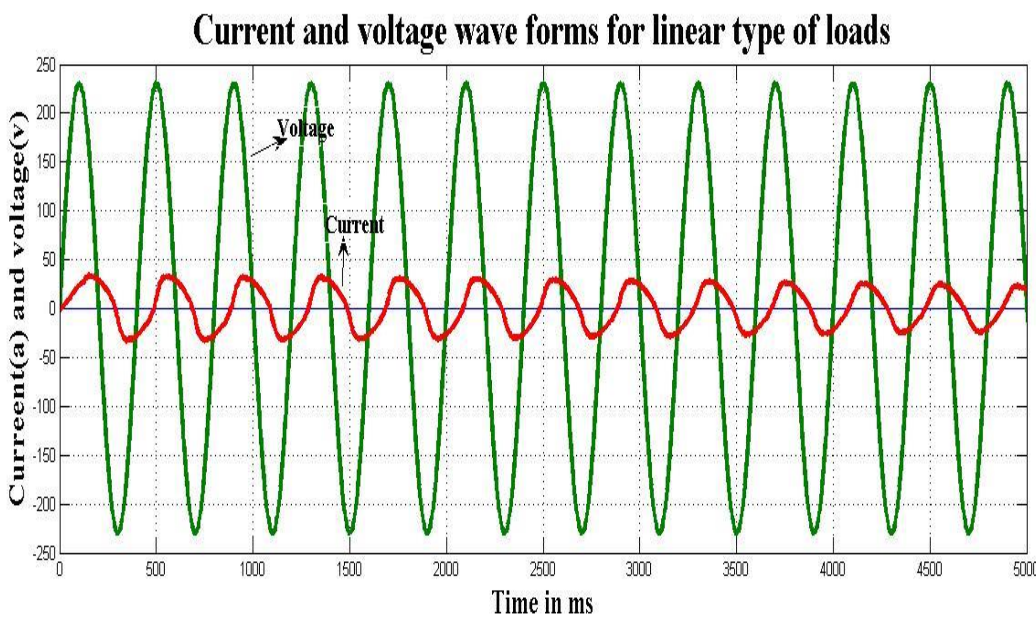

Fig 6.5 Current and voltage waveforms for linear type of loads without using reactive power compensation scheme

The fallowing figure (6.6) explains the nature total harmonic distortion present in the current without applying the reactive power compensation scheme. The total harmonic distortion level is about 19.83 percentage for liner type load like inductive type of load. The fallowing figure displays the current wave form for 5 cycles. It gives the information about the fundamental component present in the output wave form. The fundamental component is coming about 31.63 amps out of the total load current.

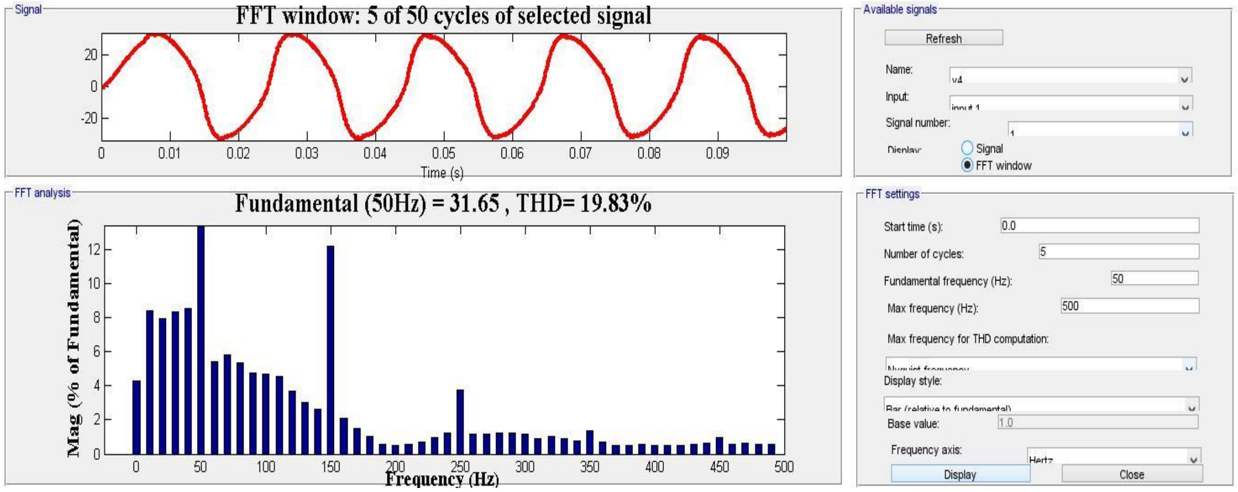

Fig 6.6 The total harmonic distortion level present for linear loads

6.4 The thd and current wave forms of the grid current for linear type of loads

The figure 6.7 displays the current and the voltage waveform s for linear type of loads after applying the reactive power compensation scheme to the inverter. The current is obtaining nearly unity power factor as shown in the figure. The current wave form is having less number of harmonics after applying the RPC scheme.

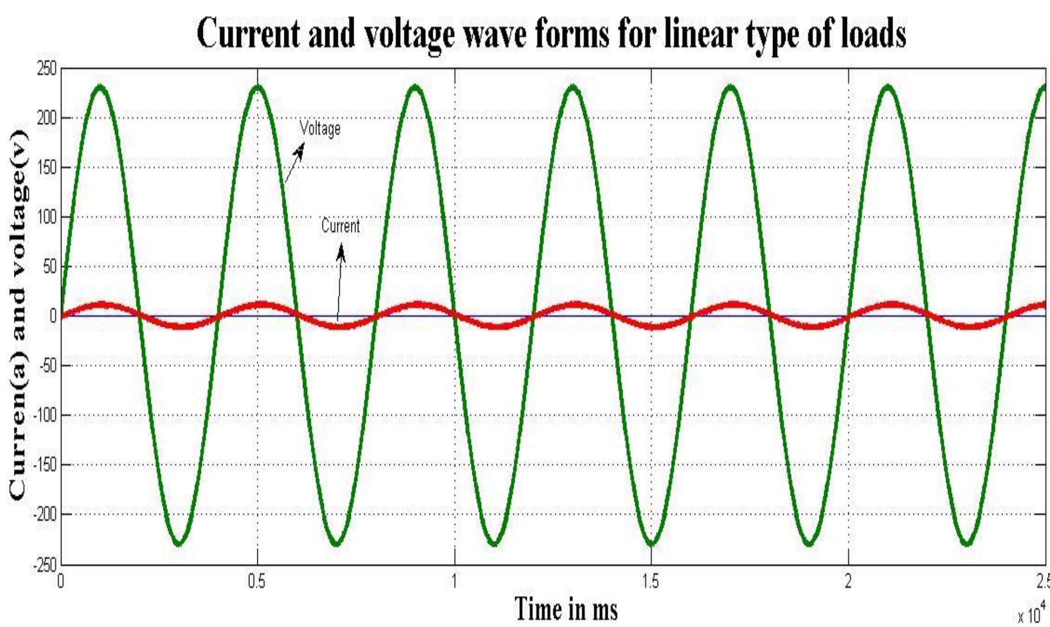

Fig.6.7 Current and voltage wave forms using reactive power compensation theory

The fallowing figure displays the total harmonic distortion level present in the output current of the grid, after applying the reactive power compensation scheme to the inverter circuit. The thd level is obtaining as 1.58 percentage. The THD level without applying the reactive power scheme is about the 19.85 percentage. The THD level reduces significantly by applying the reactive power compensation scheme.

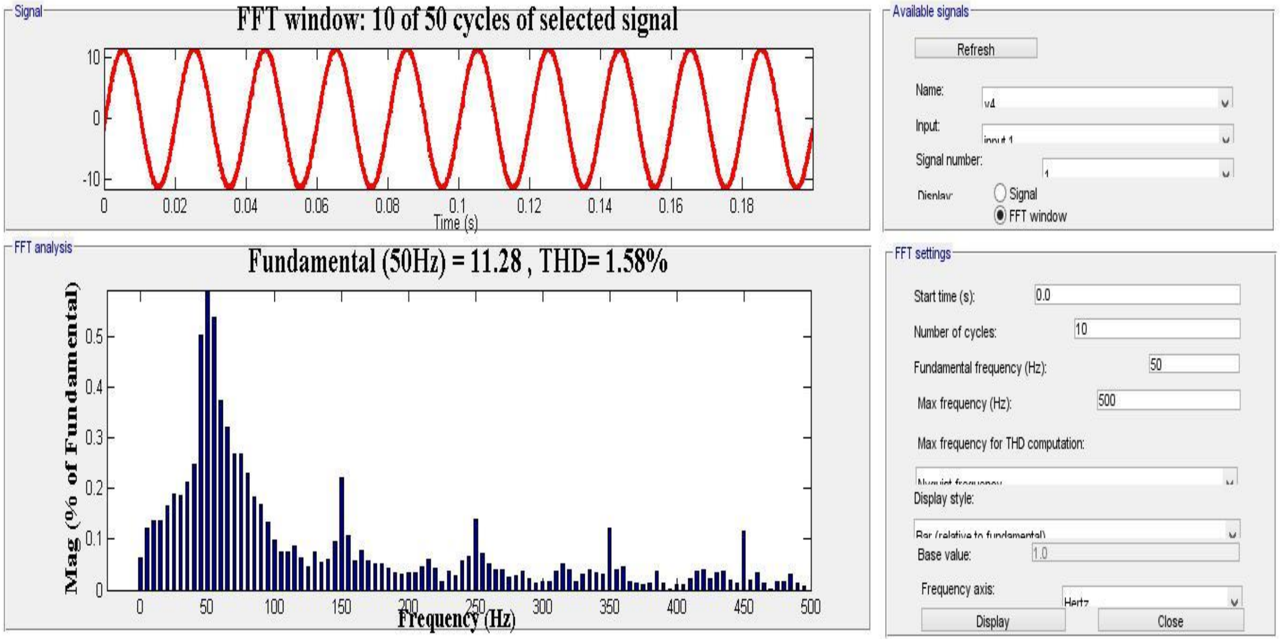

Fig.6.8 Figure displaying the total harmonic distortion level

6.5 Current and voltage wave forms for nonlinear type of loads

The figure 6.9 shows the nature of current and the voltage for nonlinear type are connected to the grid. The current wave form is of purely non sinusoidal and consists of huge number of harmonics. The current has to be made as sinusoidal for nonlinear type of loads.

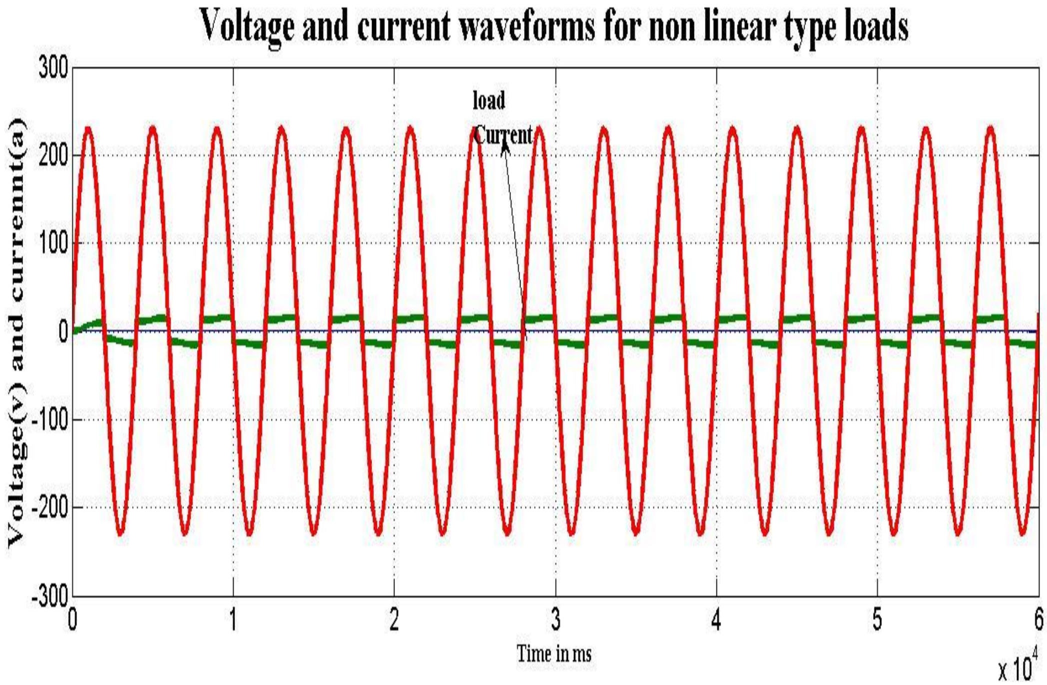

Fig6.9 The current voltage at the grid for nonlinear type of loads

6.6 current and voltage wave forms for nonlinear type of loads after applying reactive power compensation scheme

The figure 6.10 shows the voltage sand current wave forms for nonlinear loads involving the power electronic loads. The actual current is having huge number of harmonics. After applying the reactive power scheme the compensating is provided by the inverter combination. And the grid provides only the sinusoidal current required at the grid. The power factor also improves a lot after applying the reactive power compensation scheme.

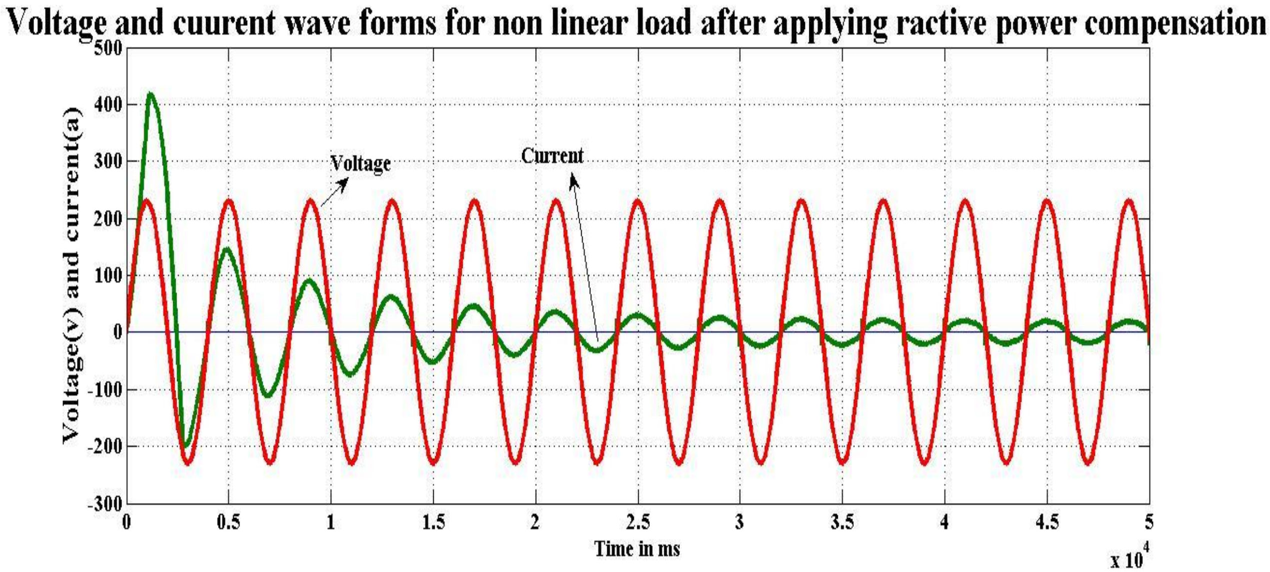

Fig.6.10 voltage and current wave forms for nonlinear loads after applying the RPC scheme

6.7 The grid current, load current, compensating current wave forms after applying the reactive power compensating scheme

The following figures 6.11,6.12,6.13 shows the grid current supplied at by it after the filter action, load current drawn by the power electronic type load, and the compensating current supplied by the solar cell. The compensating provided by the inverter circuit makes the grid current to be more sinusoidal. The fallowing diagrams explains how the compensating current compensates the harmonic content

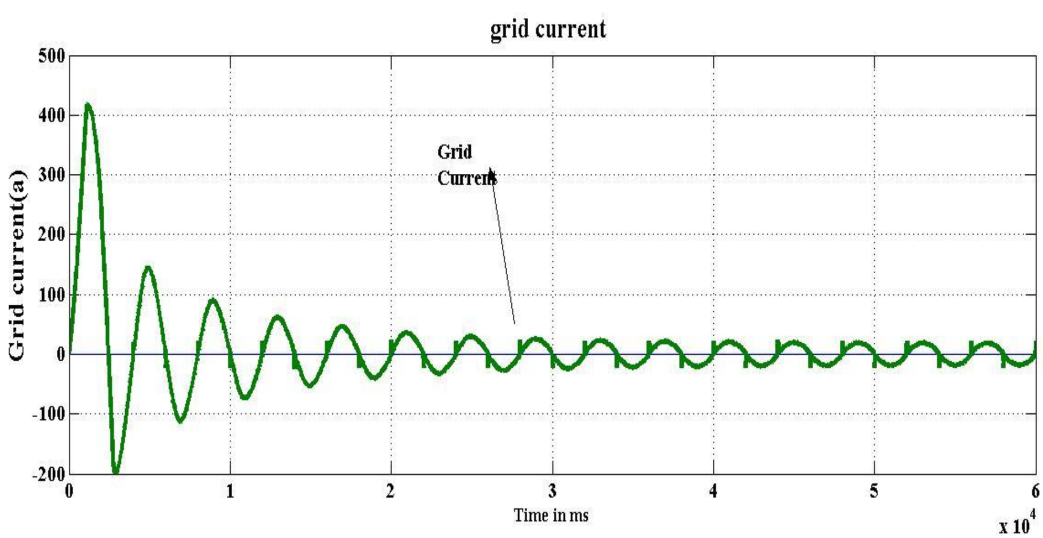

Fig.6.11 Grid current for nonlinear type of loads after applying filtering

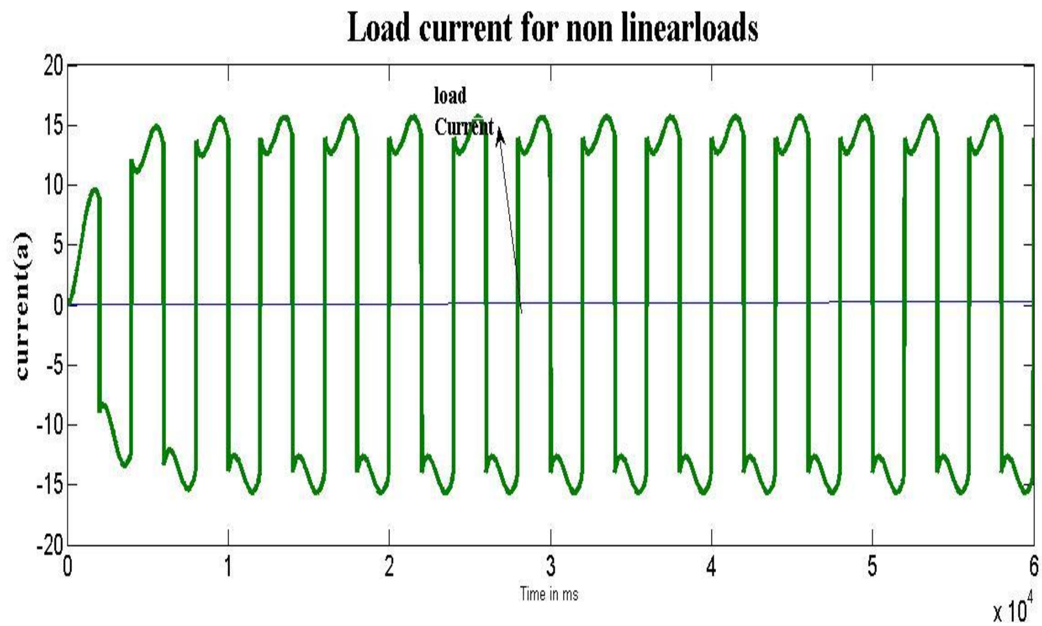

Fig.6.12 Load drawn by the nonlinear load

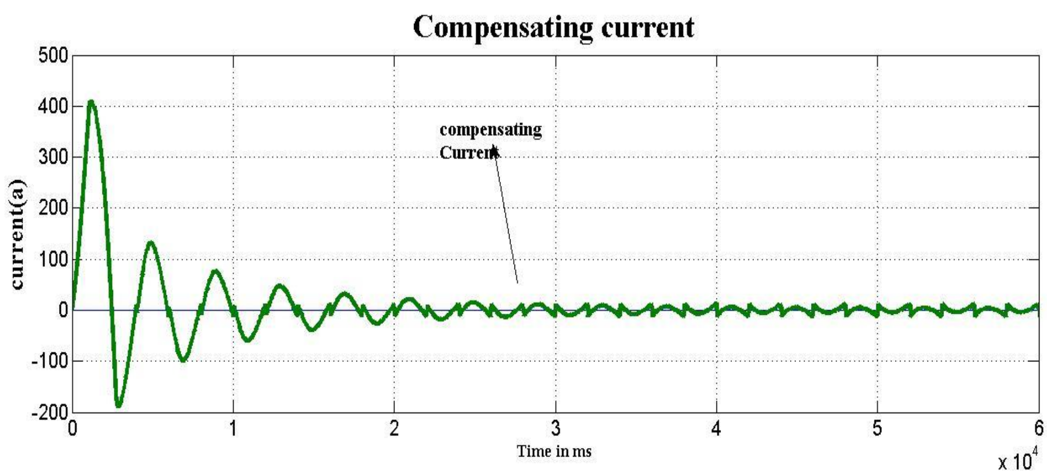

Fig.6.13 Compensating current from inverter

Conclusions and Discussions

This report gives the simulation of Photovoltaic cell with various methods like direct simulation; mat lab tool box, diode equivalent model and the results are compared for these methods. And the output voltage and current, output power versus voltage are observed at different irradiance and temperature conditions. The maximum power variation with the parameters are observed. The MPPT techniques for photovoltaic cells are developed and the output characters tics are observed at different observed. The boost converter applying the maximum power point technique is explained. The operation of boost converter at different operating conditions like turn on and turn off conditions are observed. The input and output voltages applied for the boost converter are shown and its importance is explained. The combination of boost converter with maximum power point tracking controller makes the converter to obtain the maximum power from solar cell. The operation of the inverter is explained with its different operating modes are the graphs for current-voltage and power to voltage are observed under different methods. The grid current and the voltage are observed with and without p-q reactive power compensation theory.

Future work

The characteristics of photovoltaic cells can be improved using different topologies, reactive power theory can be extended to the nonlinear loads also. Fuzzy logic controller schemes can be applied for the power quality improvement. This control scheme can be extended to three phase systems also

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